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NEW TECHNIQUES FOR ASSESSING DAMAGE FROM ACCIDENT INVESTIGATIONS

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AVIATION CRASH INJURY RESEARCH
PHOENIX, ARIZONA
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The well-being of the human occupant is of foremost importance in the design of an aircraft. Volumes of regulations and specifications delineate requirements for the production, operation, and maintenance of aircraft in an effort to insure that the vehicle possesses the maximum airworthiness characteristics consistent with the latest state of the art. Despite all our efforts in this area, accidents continue to occur. Evidence indicates that, from the point of view of forces involved at impact, the majority of these accidents can be classified as survivable. Yet, an aircraft accident without a serious injury or a fatality is a rather rare event. This, then, suggests that crashworthiness is as vitally important to the design of an aircraft as is airworthiness. However, since an accident is an unplanned action, and since the cost of conducting dynamic crash tests of all types of aircraft or of installing recording instruments aboard all aircraft would be prohibitive, the only means by which the dynamics of the crash can be determined is through investigation of the wreckage.

In an effort to improve ways of determining the time sequence of physical events which occur during and immediately following a crash, new techniques are being investigated. Dr. Gregg, in a presentation made to the Flight Safety Foundation International Air Safety Seminar held in Williamsburg, Virginia, during the period 2-6 December 1962, discussed the use of concepts borrowed from the fields of psychology, mathematics, and systems engineering as they are being applied to this area. His presentation is being published as a technical report by this Command in order to acquaint military safety personnel with the advances being made in the aircraft accident investigation field.

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INTRODUCTION

The investigation of aviation accidents is a complex and perplexing task. There are many different reasons why we want to make sense out of the often conflicting pieces of information that are associated with the event. These reasons may at times lead to incompatible conclusions. For example, it may be desirable from a regulatory point of view to establish the primary human agent responsible for the accident. Yet, it is abundantly clear that most accidents are the result of a chain of circumstances, usually unforeseeable, that compound into a critical condition. Accidents are the result of many causes and many agents.

Investigation methods are, in themselves, creative processes. It is impossible to have available all the information that one would like to have to reconstruct the circumstances surrounding an accident. The methods, therefore, provide ways of narrowing down the possibilities--what might have been -- to the point where "what must have been" is a reasonable inference from whatever facts are known.

The particular phase of accident investigation that this report is directed toward is that of describing the physical characteristics of the accident itself. We will not concern ourselves with the causes of the accident, nor will we consider the problem of establishing human responsibility. The focus will be the dynamics of a crash--the time sequence of physical events at impact and for the very brief period thereafter during which the crash energy is dissipated in the physical break-up of the aircraft.

There are two reasons why this aspect of accident investigation is important. First, a knowledge of the magnitudes and directions of the forces during the crash is essential to an understanding of the mechanisms of human injury and, hence, to the problem of providing adequate protection for the human occupant in the event of a crash. Second, since the patterns of forces depend on the structural characteristics of the vehicle, an adequate description of the crash is a necessary condition for proposing engineering design changes in the aircraft in an attempt to make the aircraft more crashworthy.

Postcrash observations of the wreckage of the aircraft are the only truly objective data that we have available. It is from these observations that the set of facts leading to description must, in general, be drawn. Of course, the use of flight recorders will be of tremendous value, but we expect only limited use of these devices and they will be restricted to the larger aircraft. As a result, this report will stress ways of assessing damage without recourse to other possible sources of information.

The "new techniques" referred to in the title are borrowed from well-established fields of knowledge: psychology, mathematics, and systems engineering. A detailed discussion of each one would be impossible, but I hope to indicate the general nature of the borrowed concepts and to show how these concepts are related to the task of assessing damage in ways that will lead to a better understanding of crash dynamics.

PSYCHOLOGICAL TECHNIQUES

Psychological scaling principles have relevance for the problem of obtaining reliable observations of the degree of damage to the aircraft. This aspect of damage assessment requires that meaningful numerical values be assigned to the damaged aircraft components. Psychologists, more than any other professional group, have been faced with the general problem of assigning numbers to things that do not lend themselves to the more usual measurements of physics. The basic idea is to provide a method that will insure that different investigators evaluating the same objective evidence will report the same conditions of damage. Reliability, in this case, means agreement.

The scaling principles and statistical methods associated with them provide the tools for eliminating the biases and variability that tend to accompany these evaluations. An example of bias might be as follows: An accident investigator learns that the pilot of a light aircraft has been killed in a crash. On arrival at the site, he begins his examination of the wreckage with the preconceived notion that the impact must have been substantial. Otherwise, how would the pilot have suffered fatal injury? The prior knowledge has produced a biasing effect that might well lead to selective viewing of the wreckage and, as a consequence, overestimation of degree of damage.

All of us try to be systematic and objective, but the fact remains that, no matter how hard we try to recognize them, subtle influences can affect what we see or hear or think. One suggestion that has been made to overcome some of the shortcomings of individual field investigation is now being explored more fully. Photographs of the accident site and of the wreckage can be presented to analysts under controlled conditions. An analyst may not be under the same time pressure that a field investigator is. The photographic record is permanent, and it can be studied by a number of independent raters. There are many specific questions that arise in connection with the use of photographs. Which photographs should be taken? How many? At what angles and distances? These questions are being attacked experimentally. The results are encouraging. And we suppose that considerable improvement in reporting this aspect of the aviation accident will soon be possible.

Another technique drawn from the same field enables us to use more completely and more powerfully the kind of information provided by the estimates of degree of damage. From these estimates we want to be able to say something about the impact conditions and the crash sequence. We are also interested in the injuries that the occupants incur. How was the person injured? Were the injuries a direct result of forces that exceeded human tolerance to abrupt decelerations? Were the injuries the indirect result of restraint system failure or other secondary conditions?

The basic idea of psychological test theory is the prediction of something called the criterion from a battery of tests called the predictor variables. Selection programs in industry and the military make use of this idea. The separate tests in the battery each tap some aspect of human ability that makes it possible to predict future success or failure on the criterion: job performance. A very large body of statistical techniques and concepts has developed so that the right combinations of tests can be determined.

Although the time relationships are exactly backwards, the same idea can be applied to the aviation accident. The postcrash damage estimates become the predictor variables; the impact conditions, the criterion. The methods of multiple correlation analysis are already proving to be fruitful in telling us what aspects of damage we should pay particular attention to and how we should put these together in ways that lead to accurate reconstruction of the initial impact. Similarly, the prediction of degree of injury, on a statistical basis, can be made from knowledge of impact and damage relationships. Here the cause-effect sequence is in the more usual direction: impact first, then injury.

MATHEMATICAL TECHNIQUES

Although the concepts mentioned above involve the use of fairly complicated mathematics, their development grew out of uniquely psychological problems. The concepts that follow are more strictly mathematical in their origins.

An aircraft striking the ground must obey physical laws. The laws are well-known and we might at first think it possible to write out mathematical expressions, equations, that describe the event precisely. The fact that aircraft structures deform, break, twist, and so on means that the physical properties of the structure change markedly and that the physical relationships are nonlinear, even discontinuous, in time. Hence, any set of equations becomes so complex that we cannot solve them.

The finite-difference methods are techniques for obtaining numerical solutions to certain sets of equations by approximation. In essence, the methods depend on representing continuous variables in space and time by values at a finite number of discrete points. Just as the motion picture has movement when the separate frames are spaced closely enough, the continuity of a dynamic process can be reproduced by analyzing it in small steps.

The implication of this idea for damage assessment is that we could reconstruct the crash sequence by approximating the structural properties of the aircraft at a number of successive stages during the time from initial impact to final rest. Just prior to impact, the flying machine has the structural integrity that its designers built into it so that it will withstand flight loads. As a result of the excessive loads at impact, and thereafter, the machine is a changed structure. The metamorphosis in reverse--no wings, no feet, no tail, no nose--occurs in successive stages; and it should be possible, given an aircraft of a particular design and impact conditions of particular values, to describe, qualitatively at least, the discrete changes in structure.

Symbolic logic is a branch of mathematics in which logical relations can be expressed as formal statements similar to the equations of ordinary algebra. An advantage of the notation is that qualitative comparisons can be drawn among classes of objects that do or do not have properties in common. The logical implications of complicated strings of expressions can be generated by applying rules to the expressions. In short, this concept makes it possible to trace out in a systematic way various relationships among objects--relationships that are too difficult to comprehend in any other way.

What does this have to do with damage assessment in aircraft accidents? The basic logic of the physical changes in the aircraft demands that a certain minimum magnitude of force must be transmitted to a structural member if it is to collapse or break. Patterns of collapse or break-up must be associated with the manner in which the structure absorbed the impact energy. The symbolic notation provides a convenient form for building lists of possible outcomes. And we would expect that, within limits, a particular pattern of damage would be associated with a particular crash sequence.

The application of these mathematical concepts to the assessment of damage leads to a set of facts quite different from any others currently available.

These ideas must be put together in some fashion so that useful deductions about aircraft design and performance under crash loads are possible. Just having a long list of possibilities is not enough. We should be able to test the adequacy of the accident description by checking against the damage resulting from known impacts. Such data are provided by the AvCIR crash testing program of full-scale helicopters. Further, we should be able to convert the lists of facts into a form that can be used by aircraft designers to increase the crashworthiness of the aircraft they build. We should be able to evaluate an aircraft of new design so that its probable break-up characteristics under typical impact conditions are predicted before that aircraft is ever involved in a crash.

To do these things requires having a model or formula that acts on the facts to produce the desired outcomes. From the field of system and communications engineering, a way of realizing this can be borrowed. The advent of high-speed digital computers and new techniques for programming these machines to process logical information provide the means for bringing order to what would otherwise be a humanly impossible task. Complex information processing systems of incredible magnitude are today simulating behaviors that are just as elaborate as those generated in the crash of an aircraft.

We can anticipate how such a system, when completed, will operate. Given certain information about a current aircraft and the terrain features on which the aircraft struck, a list of damaged parts is prepared and coded for the computer. With this input, the machine executes a program that traces the logical interconnections to find the particular combination of forces that satisfies the assessed damage. As output, values of the peak deceleration, maximum vertical or horizontal components of force, the probable times at which successive impulses occurred, or other values that may be of interest are produced. Or, by specifying certain information about the structure of an aircraft which has just been designed, and providing as input information about an expected impact, the probable damage that will result from the hypothetical crash will be produced as the output.

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